CALIFORNIA
ENERGY
COMMISSION

Tier 1

A New Energy Standard for State Buildings

CONSULTANT REPORT

DRAFT

JULY 2000
P400-00-019

Gray Davis, *Governor*

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Contractor Report

2001 Update - California Nonresidential Energy Efficiency Standards

TIER 1 A New Energy Standard for State Buildings

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This Contractor Report, prepared by Eley Associates contains a prescriptive and performance methodology for demonstrating that a new state building consumes at least 20 percent less energy than a Title 24, minimally compliant, building. Also included is a Best Practices section that contains and refers to valuable design guidelines and resources that are available to design professionals. This report is intended to be used as a discussion topic at a Staff Workshop to be held at the California Energy Commission on September 25, 2000. The workshop purpose is to obtain public comment on possible revisions to the Title 24 Building Energy Efficiency Standards (California Code of Regulations, Title 24, Part 6).

September 15, 2000

DRAFT

Tier 1

A New Energy Standard for State Buildings

Submitted to
California Energy Commission

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1. Introduction

Currently all State buildings are required to demonstrate compliance with Title 24, the State Energy Code. The goal of Tier 1 is to require that all new state buildings consume at least 20% less energy than a minimally compliant building. Tier 1 is both a prescriptive and a performance methodology for demonstrating that a new building has achieved the 20% goal.

Under the Tier 1 Prescriptive Method, the design team must first demonstrate that the building complies with Title 24, then the design team must demonstrate that the building complies with all of the relevant prescriptive requirements in the Tier 1 Prescriptive List. The authors of Tier 1 have demonstrated that a building that complies with the Tier 1 Prescriptive List will be at least 20% better than Title 24.

Like the Title 24 Performance Method itself, the Tier 1 Performance Method is designed to afford the design team the greatest flexibility in fulfilling the requirement. Under the Tier 1 Performance Method, the design team must use the Title 24 Performance Method and must show that the building uses at least 20% less source energy than the Title 24 standard building when considering only regulated end-uses. Regulated end-uses include HVAC, interior lighting, and domestic hot water, but do not include, exterior lighting, plug loads, process loads, etc.

2. Background

2.1. Buildings and the Environment

Energy use in buildings accounts for over 60 percent of the electricity used in the United States and almost 40 percent of the natural gas. Energy production and use has lead to increasing environmental degradation in the form of oil spills, acid rain, smog and other forms of pollution. The most serious impact of energy use in buildings may turn out to be the contribution to global climate change as a result of the Greenhouse Effect.

2.2. Economics

Most well designed buildings today are considerably better than the energy code minimum. Good architects and engineers recognize that the greatest value to the owner usually means going beyond the minimum. For example, the minimum efficiency for a 600 ton, water-cooled, R-143a chiller is 0.75 kW/ton. It would be difficult for a design engineer to find a chiller that inefficient. The most cost-effective efficiency level for a chiller of this type today is probably around 0.50 kW/ton, which is 33% better than the minimum requirement.

Government buildings have even greater opportunities than private-sector buildings for cost-effectively exceeding the code minimum because of the lower cost of capital. With the private sector in mind, “Most of the efficiency measures in Title 24 have a pay back period of less than 5 years” (Nonresidential Manual p. 1-1). The Department of Energy and the Office of Management and Budget recommend real discount rates of 3.5 to 4.1% for capital investment projects (NIST Handbook 135). This corresponds to pay back periods in the 10 to 15 year range.

Examples of recent public buildings in California that are considered to have cost-effectively exceeded Title 24 requirements by at least 20% include: Capitol Area East End Complex (at least 30% below Title 24), City of San Diego Ridgehaven Building (61% below), City of Santa Monica Public Safety Facility (at least 40%).

2.3. Leadership

Recently, President Clinton ordered federal agencies to cut their energy use 35% by the year 2010, saying the government should be at the forefront in cutting greenhouse gas emissions. "As the single largest consumer of energy in our country, the federal government should be leading the way. That is why today I am directing all federal departments and agencies to take steps to markedly improve the energy efficiency of our buildings."

The Governor of California could make a similar announcement, saying that "new state buildings will be held to a standard higher than the code minimum because it makes sense economically and because it's the right thing to do for the environment and for our future…"

A recent report by the Office of Technology Assessment showed that the use of cost-effective, commercially available technologies could reduce total building energy use by about one-third by 2015.

2.4. Market Transformation

One of the reasons that higher efficiency equipment is more expensive that lower efficiency models is that the demand for high end units is not as great. Production volumes are larger for the less efficient equipment which drives down the cost of these models. When a major building owner like the Federal or State government starts demanding higher efficiency equipment, production volumes increase, competition for high end equipment increases and R&D increases. All these factors can transform the market and drive down the cost of better equipment.

3. Performance Approach

Like the Title 24 Performance Method itself, the Tier 1 Performance Method is designed to afford the design team the greatest flexibility in fulfilling the requirement. Under the Tier 1 Performance Method, the design team must use CEC-certified Alternative Calculation Method (ACM) Software and must show that the building uses at least 20% less source energy than the Title 24 standard building when considering only regulated end-uses. Regulated end-uses includes HVAC, interior lighting, and domestic hot water, but does not include, exterior lighting, plug loads, process loads, etc. For example, if the simulation results for the standard building are as follows:

	Heating	Cooling	Lighting	Receptacle	Fans	Heat Rejection	Pumps	Process	DHW	Total
Standard Building	30.95	24.41	38.34	24.19	9.78	0	3.8	0	2.5	133.97
* Values are in kBtu/ft²-yr of Building Conditioned Floor Area										

Then total regulated standard building source energy = Total – Receptacle – Process = 109.78. Therefore, regulated proposed building source energy must be less than 0.8 x 109.78 = 87.82.

4. Prescriptive Approach

Under the prescriptive Tier 1 approach, the design team must first demonstrate that the building complies with Title 24, then the design team must demonstrate that the building complies with all of the relevant prescriptive requirements in the Tier 1 Prescriptive List. Each of the following list of prescriptive measures is life-cycle cost-effective (See Appendix 1 for cost-effectiveness analyses). A designer that complies with all items on the Tier 1 Prescriptive List will achieve the 20% goal. If the designer is unable to comply with <u>all</u> applicable items on the list then he/she must use the Tier 1 Performance Approach.

4.1. Lighting

Total Adjusted Actual Watts of lighting shall be at least 20% less than Total Allowed Watts. Total Adjusted Actual Watts is calculated by summing all installed interior lights and adjusting for any relevant controls credits for occupancy sensors, daylighting controls, etc. Total Allowed Watts may be calculated with any of the three Title 24 prescriptive lighting methods: Complete Building Method, Area Category Method, or Tailored Method.

4.2. Envelope

Title 24 allows two prescriptive methods of compliance. The Overall Envelope Approach allows tradeoffs between envelope components, as long as the proposed heat gain and heat loss are no more than the standard heat gain and heat loss (e.g. low efficiency glass can be compensated for with extra wall insulation). With the Envelope Component Approach each component must comply prescriptively. Tier 1 also allows both prescriptive approaches.

4.2.1. Overall Envelope Approach

The proposed heat gain and the proposed heat loss must be at least:

15% less than the standard heat gain and heat loss in Climate Zones 2-10

10% less than the standard heat gain and heat loss in Climate Zones 1,11-16

4.2.2. Envelope Component Approach

4.2.2.1. Roofs

Title 24 prescriptive roof requirements are met by meeting either the insulation R-value requirement <u>or</u> the U-factor requirement for both wood and metal frame construction or assembly. Similarly, under Tier 1 either the R-value or the U-factor requirements must be met.

	Title 24		Tier 1
	Zones 1-5, 11-16	Zones 6-10	All Zones
R-value	19	11	19
U-factor	0.057	0.078	0.057

4.2.2.2. Walls

Title 24 prescriptive wall requirements are met by meeting either the insulation R-value requirement <u>or</u> the U-factor requirement for both wood and metal frame construction or assembly. Similarly, under Tier 1 either the R-value or the U-factor requirements must be met.

	Title 24		Tier 1
	Zones 1, 11-16	Zones 2-10	All Zones
R-value	13	11	13
U-factor			
Wood Frame	0.084	0.092	0.084
Metal Frame	0.182	0.189	0.182
Mass 7-15 HC	0.340	0.430	0.340
Mass >15 HC	0.360	0.650	0.360
Other	0.084	0.092	0.084

4.2.2.3. Floors/Soffits

Floors/soffits can meet either the insulation R-value requirement or the U-factor requirement.

	Title 24			Tier 1		
	Climate Zones			Climate Zones		
	1, 16	2-10, 14-15	11-13	1, 16	2-10, 14-15	11-13
R-value	19	11	11	19	13	13
U-factor						
Mass>7	0.097	0.158	0.097	0.097	0.158	0.097
Other	0.050	0.076	0.076	0.050	0.076	0.076

4.2.2.4. Glazing

4.2.2.4.1. Windows

Windows must meet both the U-factor and the RSHG requirements. There are a number of ways to satisfy the new RSHG requirements in Zones 2-10 including low-e coatings, tints, and/or overhangs. One way to think about the new requirement is that the standard has effectively changed from single tinted to double tinted in these Zones. In addition to energy savings, this has considerable comfort benefits by reducing the "radiation effect" in hot and cold weather. Greater comfort will improve worker satisfaction, health and productivity.

	Title 24		Tier 1
	Zones 1, 11-16	Zones 2-10	All Zones
U-factor	0.72	1.23	0.72
RSHG			
North	0.77	0.82	0.77
Non-North	0.50	0.62	0.50

4.2.2.4.2. Window Area

The total window area shall not exceed 25% of the gross wall area. (Title 24 currently allows 40%).

4.2.2.4.3. Skylights

Skylights must meet the U-factor and SHGC requirements.

	Title 24		Tier 1
	Zones 1, 11-16	Zones 2-10	All Zones
U-factor	0.85	1.31	0.85
SHGC			
Transparent	0.44	0.61	0.44
Translucent	0.70	0.75	0.70

4.3. Mechanical

4.3.1. Motors

All motors shall be National Electrical Manufacturers Association rated premium efficiency.

4.3.2. Unitary Air Conditioners and Condensing Units

	Title 24	Tier 1
Air Source < 65,000 Btuh	10 SEER	12 SEER
Air Source 65,000 – 135,000 Btuh	8.9 EER	10.3 EER
Air Source 135,000 – 240,000 Btuh	8.5 EER	9.7 EER
Air Source > 240,000 Btuh	8.5 EER (8.2 if >760KBtu)	10.0 EER
Water Source < 65,000 Btuh	9.3 EER	12.0 EER
Water Source 65,000 – 135,000 Btuh	10.5 EER	11.5 EER
Water Source* > 135,000 Btuh	9.6 EER	11.0 EER
Condesning units, water or evaporative cooled	12.9 EER	12.9 IPLV
* Includes Evaporative Condenser and Evaporative Pre-Cooled Condenser		

4.3.3. Heat Pumps

	Title 24	Tier 1
Air Source < 65,000 Btuh	6.8 HSPF, 10.0 SEER	7.6 HSPF, 12.0 SEER
Air Source 65,000 – 135,000 Btuh	8.9 EER, 3.0 COP	10.1 EER, 3.2 COP
Air Source >135,000 Btuh	8.5 EER, 2.9 COP	9.3 EER, 3.1 COP
Water Source 65,000 – 135,000 Btuh	10.5 EER, 3.8 COP	13.0 EER, 4.5 COP

4.3.4. DX Equipment Accessories

Tier 1 Standard	Title 24 Requires
Package, split, or air- source heat pump system (> 50,000 Btu/h) • Integrated differential air economizer	Air or water economizer if > 75,000 and 2,500 CFM
Indirect or Direct/Indirect Evaporative Outside Air Pre-Cooler required on all Rooftop Package Units over • 25 tons in N. Coast (Climate Zones 2 - 5) • 20 tons in S. Coast (Climate Zones 6 - 10) • 15 tons in Central Valley (Climate Zones 11-13) • 40 tons in Mountains (Climate Zones 1, 16) • 10 tons in desert (Climate Zones 14, 15)	No requirements
Evaporative Pre-Cooled Condenser or Evaporative Condenser required on all Rooftop Package Units over10 tons in Climate Zones 11-15, and over 100 tons in all other Zones	No requirements

4.3.5. Chilled Water System

Tier 1 Standard	Title 24 Requires
Maximum power consumption of water cooled chiller at full load • <150 tons: 0.74 kW/ton • 150-300 tons: 0.67 kW/ton • 301-600 tons: 0.6 kW/ton (or 0.54 kW/ton with CFC refrigerants) • >601 tons: 0.55 kW/ton (0.50 kW/ton with CFC refrigerants)	<150 tons: 0.92 kW/ton 150<300 tons: 0.84 kW/ton >=300 tons: 0.75 kW/ton (or 0.68 kW/ton with CFC refrigerants)
Maximum power consumption of air cooled chiller at full load • all sizes: 1.2 kW/ton	<150 tons: 1.30 kW/ton >150 tons: 1.41 kW/ton
Unloading Mechanisms (air and water cooled chillers; only required on one chiller if plant contains multiple chillers): • Unloaders on Reciprocating chillers • VSD or dual compressor on Centrifugal • VSD on Scroll chillers over 200 tons	No requirements

4.3.6. Cooling Towers

Tier 1	Title 24 Requires
Approach temperature: <=10°F at design conditions	No requirements (ACM std bldg. Uses 10°)
>= 50 gpm/bhp at CTI conditions (95/85/78WB) for open-loop >= 30 gpm/bhp at CTI conditions for closed-loop (fluid coolers)	No requirements (ACM uses 0.013 EIR = 39 gpm/bhp)
Multiple stage or variable speed tower fan motor	No requirements (ACM std bldg. Uses 2 speed)

4.3.7. Air Handling Units

Tier 1 Standard	Title 24 Requires
Install integrated differential air economizer on all rooftop air handling units.	Air or water economizer if > 75,000 btuh and 2,500 CFM
Indirect or Direct/Indirect Evaporative Outside Air Pre-Cooler required on all air handling units over 15 tons in Climate Zones 11-15	No requirements
Air-Air heat recovery on units where min OA > 50% total CFM, and total CFM > 20,000 in Climate Zones 1,11-16	No requirements
Demand control VAV ventilation with CO_2 sensors on units serving spaces with design conditions of at least 100 people and <= 50 ft²/person. System must be designed to allow terminal units to modulate down to min air flow (0.15 cfm/ft²) during on-	No requirements

hours when CO_2 and temperature requirements are met.	
CO or CO_2 controlled VAV garage ventilation systems for all garage spaces over 5,000 ft².	No requirements

4.3.8. Water Distribution Systems

Tier 1 Standard	Title 24 Requires
Variable speed pumping required on chilled water and hot water loops over 300 GPM (Primary Constant Speed/Secondary Variable Speed is acceptable)	No requirements

4.3.9. Fan Power Consumption

Tier 1 Standard	Title 24 Requires
The following fan power consumption requirements apply to all systems with fan power index > = 5 hp • Maximum variable speed fan power index: 1.0 Watts/cfm • Maximum constant speed fan power consumption: 0.72 Watts/cfm • VSD on all VAV fans over 5 horsepower.	Applies only to systems > 25 hp • Variable 1.25 W/cfm • Constant: 0.8 W/cfm • VSD on VAV > 25 hp

The Tier 1 fan power requirements are standard practice today and should have no cost impact. Unfortunately, the current ACM Method does not give any credit for the Tier 1 fan power requirements since the standard design mirrors the proposed design fan system.

5. Best Practices

Beating Title 24 by 20% does not tell the whole story about the energy efficiency and comfort of a building. There are a number of limitations of Title 24 (and Tier 1 by extension). For example, improving a building's shape or orientation will reduce energy use but will not help achieve or exceed Title 24 because the Title 24 standard building assumes the same shape as the proposed building. Other examples of this sort of "moving target" or "chasing your own tail" include Title 24's treatment of window area and fan power. Furthermore, Title 24 addresses only design, not construction or operation. A well designed building can easily end up being a real "energy hog" if it is not constructed, operated and maintained according to the design intent. Thorough ommissioning is the best way to insure that an efficient design is properly implemented.

This section contains only a small snapshot of some of the design guidelines and design resources that are available to design professionals.

5.1. HVAC

A few general guidelines for the mechanical engineer to consider include:

1. Electronic controls are a must. EMS capabilities should include:
    - Night setback
    - 7 day programming

- Optimal start (based on outside and inside temperatures)
- Adjustable deadband (difference between cooling and heating setpoints should always be at least 3°F)
- Supply air temperature reset (based on warmest zone or outside temperature)
- Isolation zones (after-hours HVAC requests should only bring on one air handler or package unit)

2. When using hot water for heating, consider using multiple or staged boilers for low load period. This will save substantial energy at low loads.
3. Consider under floor air distribution. In addition to reduced fan power and better heat and pollutant removal, the higher supply air temperature allows for longer free cooling (i.e. extended economizer range) and the exposed slab allows effective pre-cooling (with outdoor air). The higher supply temperature also allows chillers to run more efficiently. Perhaps the greatest savings, however, come from the ease with which under floor systems can be reconfigured as tenant layouts change.

5.1.1. HVAC Design Resources

CoolTools

The PG&E CoolTools project objective is to develop, disseminate and promote an integrated set of tools for design and operation of chilled water plants. The CoolTools products are software programs, publications and support services that together provide an objective analytical method for comparing alternatives during the design and operation of chilled water systems. CoolTools supports a new standard of practice for achieving cost effective and efficient equipment selection, system design and operating scenarios. CoolTools products are Internet based, public domain resources, and are targeted to building owners, design professionals, and operators involved in both new construction and retrofits.

Reference: http://www.pge.com/pec/cooltools/index.html

ACEEE Guide to Energy-Efficient Commercial Equipment

The Guide focuses on design, operation and maintenance issues for lighting, HVAC, and motors.

Reference: Suozzo, Margaret, Jim Benya, Mark Hydeman, Paul DuPont, Steven Nadel and R. Neal Elliott. 1997. *Guide to Energy-Efficient Commercial Equipment*. Washington D.C.: American Council for an Energy-Efficient Economy. http://www.aceee.org/

HVAC Design Wizard

The Eley Associates HVAC Design Wizard is a software component that leads the user through the initial process of specifying a complete HVAC system. For each design decision, the HVAC Wizard recommends choices that are life-cycle cost effect for the particular situation.

Reference: www.eley.com

California Detention Facilities Design Guide

A useful resource for the design of energy-efficient adult and juvenile detention facilities.

Reference: California Energy Commission

Reference Specifications for Energy and Resource Efficiency

The goal of this CEC-funded research project is to develop a set of reference specifications for architects, engineers, and lighting designers to select from and insert into their construction documents. The focus is on energy-efficient envelope, HVAC, and lighting design through the specification of components, systems, and controls with strong emphasis on performance monitoring and commissioning of those systems.

Reference: www.eley.com/specs/

Energy Design Resources

Southern California Edison's Energy Design Resources Website offers a series of publications and other resources about design techniques and energy efficient technologies relating to integrated energy design, HVAC, lighting, drivepower, building commissioning, and energy management systems.

Reference: http://www.energydesignresources.com/

FEMP Procurement Guide

The Federal Energy Mangement Program's (FEMP) Guide to Buying Energy Efficient Products covers residential and commercial HVAC and DHW equipment, office equipment, lighting technologies, envelope products, etc.

Reference: http://www.eren.doe.gov/femp/procurement/begin.html

5.2. Lighting

Good lighting distribution, control of glare, and control of contrast all promote occupant health and satisfaction. Below are some guidelines for achieving these objectives. For additional guidance consult the Lighting Design Resources.

1. All surfaces within a room should be considered an integral part of a lighting system. Light colored finishes should be used, especially above table height, because they reflect light to other surfaces within a room. On the other hand, dark surfaces should be avoided because they absorb light and require that additional energy be used to provide adequate illumination, occupant comfort and satisfaction. It is important to coordinate the choice of office furniture color with the lighting design.
2. Adequate vertical illumination and ceiling illumination are important for occupant satisfaction. However, providing good vertical and ceiling illumination should never increase energy use. Rather, using indirect, or indirect/direct lighting systems; strategic placement of ceiling luminaires close to walls; grazing of wall surfaces with wall mounted fluorescent luminaires or fluorescent wall sconces; effective use of daylighting; and the use of light colored surfaces can all be used to improve vertical and ceiling illumination without increasing energy use.
3. In office environments, provide low ambient (30 foot-candles or less) illumination from a ceiling mounted system, and augment individual tasks with fluorescent task lights mounted on office furniture as needed. However, calculated Lighting Power Densities (LPD's) should always include the contributions from both the ceiling plus the task lighting systems. Designers are encouraged to consider indirect, or indirect/direct lighting systems.
4. Exterior illumination should be provided with cutoff luminaires to eliminate wasting energy by illuminating the black sky, as well as improve security by reducing disability glare. Exterior should use fluorescent or HID's and be automatically controlled by photosensors.
5. Automatic lighting controls are imperative. At a minimum, use automatic controls such as occupancy sensors time scheduling, or spring timers in nearly all spaces. Employ dimming or multi-level switching in private offices and other user-controlled spaces. Consider daylighting controls in perimeter spaces, especially open offices. Consider combinations of controls such as occupancy sensors and daylighting controls.
6. The Tier 1 prescriptive requirements do not affect minimum system efficacies required by the owner. For example:
    - Interior lighting should be at least 90 lumens per watt, should have minimum CRI of 80%, etc
    - Ballasts should be high frequency electronic, high power factor, minimum harmonic

distortion, minimum current crest factor, etc.
- Compact fluorescent should be high power factor, etc,
- Exit signs should use LED's
- Exterior should use fluorescent or HID's

5.2.1. Lighting Design Resources

Illuminating Engineering Society (IES) Handbook, 9th Edition

Reference: http://www.iesna.org/

Advanced Lighting Guidelines

This handbook contains a series of guidelines on advanced energy efficient lighting technologies developed by the California Energy Commission. The handbook contains guidelines on lighting design practices, computer-aided lighting design, luminaries and lighting systems, energy efficient and electronic ballasts, full-size fluorescent lamps, compact florescent lamps, conventional shape tungsten halogen lamps, compact metal halide and white high-pressure sodium lamps.

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http://www.energy.ca.gov/water/publication/pub0133.html

5.3. Commissioning

5.3.1.1. Commissioning Agent

A Commissioning Agent should be brought on board at the same time as the design team or in the early design phase.

5.3.1.2. Commissioning Plan

One of the primary objectives of the Commissioning Plan is to clarify the design intent (sequence of operations) of all commissioned systems. The design intent indicates exactly how all systems are expected to operate under a variety of conditions, such as normal occupancy, partial occupancy, emergency situations. The Commissioning Plan also lays out the schedule for all commissioning activities (regular meetings with design/build teams, functional testing, etc.).

5.3.1.3. Sensors and Calibration

The specifications should include not only what points are to be monitored, but the type of equipment to be used and/or the required level of accuracy. Examples of the types of points that are needed for various systems include the following:

Chiller System

Chiller kW
Primary and Secondary pump kW
Primary and Secondary CHW supply flow (gpm)
Primary and Secondary Loop Supply and Return CHW temperatures
Primary Loop differential pressure
Secondary Loop differential pressures (at end of one run)
System Bypass Valve Position

System load (calculated from primary loop temperature difference and gpm)
Chiller KW/ton (calculated from Chiller kW and system load)
Cooling Tower Fan kW, Condenser pump kW
Leaving and Entering water temperature

Air Handler Units (AHUs)

Discharge static pressure
Flow at discharge (cfm)
Supply fan kW, Return fan kW
Mixed air, Supply air, Return air and Outside air temperatures
Mixed air damper position, Return air damper position
Outside air dampers position (min. damper and economizing damper)
Outside air flow (cfm)
Cooling coil valve position, Heating coil valve position
Duct static pressure
CO_2 sensor for OSA control (ppm) (if applicable)

While the Controls Contractor is typically responsible for seeing that all sensors are properly installed and calibrated, part of the Commissioning Agents responsibilities could be to independently verify the EMS recorded data under at least three different conditions (e.g. full flow, no flow, low flow). Calibration should be verified using stand-alone/hand-held equipment, visual inspection and independent calculation.

5.3.1.4. Data Storage and Visualization

The energy management system must have adequate data storage, visualization, and other features (e.g. internet access). Requirements could include the following:

- A high sampling rate (e.g. every minute) should be stored short-term (e.g. for 1 day) and hourly data should be permanently stored.
- At least six columns of data can be viewed on the screen at once and can be graphed using a graphing program integral to the control system, with at least four parameters graphed against time on the same graph. The columnar format shall have time down the left column with columns of data to the right (one column for each parameter).
- The system shall have the ability to graph real-time data of up to four points on the EMS at once, giving each point its own scale. The user should be able to easily set the time interval (e.g. last 24 hours of 1 minute data or last week of hourly data) and dates (e.g. from June 15 to July 7).
- Without any special or difficult conversions, this data shall be able to be designated to be stored as an ASCII delimited file in the same columnar format for use in graphing with normal commercial spreadsheet software.
- The system shall have the capability to graph one or more points against another, rather than just against time (e.g. kW vs. tons).
- All of the data and graphing capabilities should be accessible over the internet via standard internet browsers (Netscape or Internet Explorer).

5.3.1.5. Functional Testing

After the Contractor has corrected any sensor calibration problems and has completed Test and Balance and Start Up and before the building is occupied, the Cx (Commissioning) Agent shall conduct functional tests, with the assistance of the Contractor, that verify systems are operating efficiently under a range of possible operating conditions. The Contractor (HVAC and Controls sub-contractors) shall provide skilled technicians for the duration of the functional testing who will operate the HVAC equipment according to the instructions of Cx Agent. For each piece of equipment (chillers, towers, pumps, fans, sample of VAV boxes, etc) there is a series of test conditions (e.g. min load, max load, 50% load) and for each set of test conditions there is a series of parameters that must be recorded (e.g. CFM, kW, GPM). Prior to functional testing, the Cx Agent shall calculate the expected value of each parameter for each set of test conditions. The Design Engineer shall confirm all expected values before functional testing.

5.3.1.5.1. Sample Chiller Plant Functional Testing

I. Objectives
1. Verify that chiller, CHW pump, CW pump, and tower fan kW are minimized at all times.
2. Verify that primary and secondary CHW loop flows and heads are minimized at all times.
3. Verify that CW loop flow is minimized at all times.

II. Test Conditions
1. Peak Cooling Load
   a. Set all cooling setpoints to min (e.g. 60F) to force max cooling load.
2. 50% Cooling Load
   a. Set 50% of cooling setpoints to max, while remaining 50% remain at min. (Percentages are based on zone CFM compared to total CFM)
3. 20% Cooling Load
   a. Set 80% of cooling setpoints to max, while remaining 20% remain at min.
4. No Cooling Load
   a. Set all cooling setpoints to max (e.g. 85F) to force no cooling load.

III. Parameters
1. Chiller kW
2. Primary pump kW
3. Primary CHW supply flow (gpm)
4. Secondary Loop flow
5. Primary Loop Return CHW temperature
6. Primary Loop Supply CHW temperature
7. Secondary Loop Return CHW temperature
8. Secondary Loop Supply CHW temperature
9. Primary Loop differential pressure
10. Secondary Loop differential pressures (at end of each run)
11. System Bypass Valve Position
12. System load (calculated from primary loop temperature difference and gpm)
13. Chiller KW/ton (calculated from Chiller kW and system load)
14. Tower Fan kW
15. Tower Spray pump status
16. Tower Leaving water temperature
17. Tower Entering water temperature
18. Condenser pump kW, Hz
19. Sump level
20. OA temp

5.3.1.6. Post-Occupancy Testing

After 12 months of occupancy, the Cx Agent should review the recorded EMS data to find points in time that most closely represent all of the test conditions described in functional testing (e.g. peak load, low load, OA temp > RA temp, OA temp < RA temp, etc.). As with the functional tests, the Cx Agent shall compare actual and expected values for all parameters under all test conditions and shall make a full report.

5.3.1.7. O&M Manuals and Training

It is important that the Contractor and/or Commissioning Agent prepare complete operations and maintenance documentation and that the facility staff is adequately trained.

5.3.2. Commissioning Resources

DOE/Oregon Commissioning Toolkit

The Portland Energy Conservation Institute (PECI) has put together an excellent resource for commissioning specifications that can be downloaded for free.

Reference: http://www.peci.org/cx/index.html or http://www.energy.state.or.us/bus/comm/bldgcx.htm

ASHRAE Guideline

"The HVAC Commissioning Process," ASHRAE Guideline 1-1996. www.ashrae.org

6. Lifecycle Cost Analysis

Two typical buildings were modeled in three climate zones for a total of 6 case studies. In each case study, the total incremental cost of implementing the prescriptive standard was compared to the total energy savings. In each case it was determined that the Tier 1 prescriptive standard was life-cycle cost effective, with simple payback periods of less than 5 years.

In each of the case studies, VisualDOE 2.61 was used to determine the energy cost savings by comparing the "Base Building" and the "Proposed Building". The Base Building represents a minimally compliant Title 24 building. The Proposed Building represents a minimally compliant Tier 1 building. The incremental cost is the cost difference between the Base and Proposed Buildings.

EnergyPro 2.04 was used to Compare the Proposed Building to the Standard Building, which represents the ACM Reference Building for the Tier 1 Proposed Building. In all but one case study it was determined that the Tier 1 20% criteria was met, i.e. the Proposed Building used at least 20% less source energy than the Standard Building when comparing regulated end-uses (HVAC, lighting, and DHW). The modeling assumptions are the same for Zones 3 and 10, only the energy savings are different.

Building Type	**Climate Zone**	**Payback Period (yrs)**	**% Better than T-24**
Small Office	12 (Sacramento)	0.9	21%
	10 (Riverside)	1.3	22%
	3 (Oakland)	1.8	19%
Large Office	12 (Sacramento)	2.4	21%
	10 (Riverside)	1.1	23%
	3 (Oakland)	1.2	21%

6.1. Case Study: Small Office in Zone 12

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
Climate Zone	12 (Sacramento)	same	same	
Floor Area (ft²)	10,000	same	same	
Shape	square (equal windows)	same	same	
Stories	1	same	same	
Wall heights:	15 ft	same	same	
Ceiling heights:	6 ft	same	same	
Window wall ratio:	40% (600 ft²/façade)	25% (360 ft²/façade)	25%	
Window U value	0.72	same	same	
Window RSHG (North)	0.77	same	same	
Window RSHG (Non-North)	0.5	same	same	
Wall type	mtl R-13	same	same	
Wall U-factor	0.182	same	same	
Roof type	R-19	same	same	
Roof U-factor	0.057	same	same	
Floor/Sofit type	covered slab	same	same	
LPD	1.2	0.98	1.2	
Lighting Incr. Cost		$ -		1
EPD	1.5	same	same	
Schedules	T-24 daytime	same	same	
Min OA	15 cfm/person	same	same	
Occupant density	100 ft²/person	same	same	
HVAC System	5 Package Single Zones	same	same	
North Zone Cool Cap. (kBtuh)	62	50	50	
East Zone Cool Cap. (kBtuh)	115	83	83	
South Zone Cool Capacity (kBtuh)	123	89	89	
West Zone Cool Capacity (kBtuh)	122	87	87	
Interior Zone Cool Capacity (kBtuh)	190	182	182	
North Capacity (tons)	5.2	4.2	4.2	
East Capacity (tons)	9.6	6.9	6.9	
South Capacity (tons)	10.3	7.4	7.4	
West Capacity (tons)	10.2	7.3	7.3	
Interior Capacity (tons)	15.8	15.2	15.2	
Total Capacity (tons)	51	41	41	
North Zone EER	8.3 (SEER 10)	10.3 (SEER 12)	8.3 (SEER 10)	
East Zone EER	8.9	10.3	8.9	
South Zone EER	8.9	10.3	8.9	
West Zone EER	8.9	10.3	8.9	
Interior Zone EER	8.5	11	8.5	
Evap Pre-Cooler OA	none	Interior Zone only	none	
Evap Condenser	none	Interior Zone only	none	
Package Unit $/ton	$ 700	$ 800		2
Pkg Unit Base Cost	$ 35,700	$ 32,733		
Evap PreCool OA $/ton		$ 250		3
Evap Cool Condsr $/Ton		$ 200		4
Total Incremental Cost		$ 3,858		
Elec Util Rate	PG&E E-19S	PG&E E-19S		
Gas Util Rate	PG&E GNR-1	PG&E GNR-1		
Energy Cost Savings (vs Base)		$ 4,296		
Payback (yrs)		**0.9**		
Source Energy (kBtu/ft²-yr) (w/o receptacle)		61.8	78.56	
Percent Better Than T-24 (regulated end-uses)		**21%**		

1. The net incremental cost of a more efficient lighting system is assumed to be zero
2. Source: 1996 CADMAC (California Demand Side Management Measurement Advisory Committee)
   CADMAC cost data compiled from manufacturers, distributors, retailers, contractors, utility program files, R. S. Means, etc
3. For Direct/Indirect system. Source: CADMAC, Dupont Dobbs Engineers
4. Source: Dupont Dobbs Engineers (cost data based on 30 years HVAC design experience and current info from vendors)

6.2. Case Study: Small Office in Zone 10

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
Climate Zone	10 (Riverside)	same	same	
Floor Area (ft²)	10,000	same	same	
Shape	square (equal windows)	same	same	
Stories	1	same	same	
Wall heights:	15 ft	same	same	
Ceiling heights:	6 ft	same	same	
Window wall ratio:	40% (600 ft²/façade)	25% (360 ft²/façade)	25%	
Window U value	1.23	0.72	1.23	
Window RSHG (North)	0.82	0.77	0.82	
Window RSHG (Non-North)	0.62	0.5	0.62	
Window Incremental $/ft²		$ 3.93		3
Window Incremental Cost		$ 5,659		
Wall type	mtl R-11	mtl R-13	mtl R-11	
Wall U-factor	0.189	0.182	0.189	
Wall Incremental $/ft²		$ -		4
Roof type	R-11	R-19	R-11	
Roof U-factor	0.078	0.057	0.078	
Roof Incremental $/ft²		$ 0.50		3
Roof Incremental Cost		$ 5,000		
Floor/Sofit type	covered slab	same	same	
LPD	1.2	0.98	1.2	1
EPD	1.5	same	same	
Schedules	T-24 daytime	same	same	
Min OA	15 cfm/person	same	same	
Occupant density	100 ft²/person	same	same	
HVAC System	5 Package Single Zones	same	same	
North Zone Cool Cap. (kBtuh)	70	49	49	
East Zone Cool Cap. (kBtuh)	112	77	77	
South Zone Cool Capacity (kBtuh)	149	101	101	
West Zone Cool Capacity (kBtuh)	119	81	81	
Interior Zone Cool Capacity (kBtuh)	176	169	169	
North Capacity (tons)	5.8	4.1	4.1	
East Capacity (tons)	9.3	6.4	6.4	
South Capacity (tons)	12.4	8.4	8.4	
West Capacity (tons)	9.9	6.8	6.8	
Interior Capacity (tons)	14.7	14.1	14.1	
Total Capacity (tons)	52	40	40	
North Zone EER	8.3 (SEER 10)	10.3 (SEER 12)	8.3 (SEER 10)	
East Zone EER	8.9	10.3	8.9	
South Zone EER	8.5	10.3	8.5	
West Zone EER	8.9	10.3	8.9	
Interior Zone EER	8.5	9.7	8.5	
Evap Pre-Cooler OA	none	same	same	
Evap Condenser	none	same	same	
Package Unit $/ton	$ 700	$ 800		2
Pkg Unit Base Cost	$ 36,517	$ 31,800		
Total Incremental Cost		$ 5,943		
Elec Util Rate	PG&E E-19S	PG&E E-19S		
Gas Util Rate	PG&E GNR-1	PG&E GNR-1		
Energy Cost Savings (vs Base)		$ 4,732		
Payback (yrs)		**1.3**		
Source Energy (kBtu/ft²-yr) (w/o receptacle)		66.0	84.36	
Percent Better Than T-24 (regulated end-uses)		**22%**		

1. The net incremental cost of a more efficient lighting system is assumed to be zero
2. Source: CADMAC
3. Source: ASHRAE 90.1 life-cycle cost analysis (available in NBI Criteria Generator software)
4. Standard practice, no incremental cost

6.3. Case Study: Large Office in Zone 12

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
Climate Zone	12 (Sacramento)	same	same	
Floor Area (ft²)	200,000	same	same	
Shape	square (equal windows)	same	same	
Stories	5	same	same	
Wall heights:	15 ft	same	same	
Gross Wall Area	60,000	same	same	
Window area	24,000	15,000	15,000	
Window U value	0.72	same	same	
Window RSHG (North)	0.77	same	same	
Window RSHG (Non-North)	0.5	same	same	
Wall type	mtl R-13	same	same	
Wall U-factor	0.182	same	same	
Roof type	R-19	same	same	
Roof U-factor	0.057	same	same	
Floor/Sofit type	covered slab	same	same	
LPD	1.2	0.96	1.2	1
EPD	1.5	same	same	
Schedules	T-24 daytime	same	same	
Min OA	15 cfm/person	same	same	
Occupant density	100 ft²/person	same	same	
HVAC System	Chiller/Boiler, VAV Reheat	same	same	
Chiller tons	600	300		
Chiller kW/ton	0.75	0.6		
Chiller unloading	none	VSD		2
Chiller $/ton	$ 380	$ 550		3
Chiller Cost	$ 228,000	$ 165,000		
CHW loop gpm (using 2gpm/ton)	1200	600		
CHW (primary) loop head (ft)	25.0	25.0		
CHW pump effic	0.77	0.77		
CHW pump bhp	9.8	4.9		
motor effic (all motors)	NEMA Hi	NEMA premium	NEMA Hi	
SCHW (secondary) loop gpm	1200	600		
SCHW loop head	75.0	75.0		
SCHW pump effic	0.72	0.72		
SCHW pump bhp	31.6	15.8		
SCHW pump min flow	constant speed	20%		
Total CHW loop+pump $/ton	$ 560	$ 750		3
Total Chilled Water Loop Cost	$ 336,000	$ 225,000		
CW loop gpm (based on 2.5 gpm/ton)	1500	750		
CW loop head	40.0	40.0		
CW pump effic	0.77	0.77		
CW pump bhp	19.7	9.8		
CW Loop $/gpm	$ 33	$ 38		3
CW Loop Cost	$ 49,500	$ 28,500		
Tower approach	15.0	10.0	10.0	
Tower size (tons)	714	352		
Tower gpm/hp	20 (=0.15 bhp/ton)	50 (=0.06bhp/ton)		
Tower fan control	single speed	2 speed		
Tower $/ton	$ 97	$ 144		3
Tower Cost	$ 69,258	$ 50,688		

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
HW loop gpm	300	300		
HW loop head	50	50		
HW pump effic	0.72	0.72		
HW loop bhp	5.3	5.3		
HW loop min flow	constant	20%		
HW loop $/gpm	$ 50	$ 63		3
HW Loop Cost	$ 15,000	$ 18,750		
Supply fan CFM	260,000	220,000		
Supply fan W/CFM	1.25	1.0	1.0	
supply fan bhp	436	295		
Supply fan temp rise	3.88	3.10		
Supply fan control	VSD	same	same	
Evap Precool Direct/Indirect effectiveness	n/a	0.85/0.8	n/a	
Evap Precool fan+pump power		100 hp		
AHU base cost $/cfm	$ 2.10	$ 2.10		3
Evap Precool incr. Cost $/cfm		$ 2.50		3
Total AHU Cost	$ 546,000	$ 1,012,000		
Total Incremental Cost		$ 274,750		
Elec Util Rate	PG&E E-19S	PG&E E-19S		
Gas Util Rate	PG&E GNR-1	PG&E GNR-1		
Energy Cost Savings (vs Base)		$ 115,949		
Payback (yrs)		**2.4**		
Source Energy (kBtu/ft²-yr) (w/o receptacle)		62.5	78.87	
Percent Better Than T-24 (regulated end-uses)		**21%**		

1. The net incremental cost of a more efficient lighting system is assumed to be zero
2. VSD modeled using Trane 400 VSD EIR-FPLR curve from S. Taylor
3. Sources: Dupont Dobbs, 1996 CADMAC (California Demand Side Management Measurement Advisory Committee). CADMAC cost data compiled from manufacturers, distributors, retailers, contractors, utility program files, R. S. Means, etc. Dupont Dobbs Engineers cost data based on 30 years HVAC design experience and current info from vendors (12/99)

6.4. Case Study: Large Office in Zone 10

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
Climate Zone	10 (Riverside)	same	same	
Floor Area (ft²)	200,000	same	same	
Shape	square (equal windows)	same	same	
Stories	5	same	same	
Wall heights:	15 ft	same	same	
Gross Wall Area	60,000	same	same	
Window area	24,000	15,000	15,000	
Window U value	1.23	0.72	1.23	
Window RSHG (North)	0.82	0.77	0.82	
Window RSHG (Non-North)	0.62	0.5	0.62	
Window Incremental $/ft²		$ 3.93		4
Window Incremental Cost		$ 58,950		
Wall type	mtl R-11	mtl R-13	mtl R-11	
Wall U-factor	0.189	0.182	0.189	
Wall Incremental $/ft²		$ -		4
Roof type	R-11	R-19	R-11	
Roof U-factor	0.078	0.057	0.078	
Roof Incremental $/ft²		$ 0.50		4
Roof Incremental Cost		$ 20,000		
Floor/Sofit type	covered slab	same	same	
LPD	1.2	0.96	1.2	1
EPD	1.5	same	same	
Schedules	T-24 daytime	same	same	
Min OA	15 cfm/person	same	same	
Occupant density	100 ft²/person	same	same	
HVAC System	Chiller/Boiler, VAV Reheat	same	same	
Chiller tons	560	500		
Chiller kw/ton	0.75	0.6		
Chiller unloading	none	VSD		2
Chiller $/ton	$ 380	$ 550		3
Chiller Cost	$ 212,800	$ 275,000		
CHW loop gpm (using 2gpm/ton)	1120	1000		
CHW (primary) loop head (ft)	25.0	25.0		
CHW pump effic	0.77	0.77		
CHW pump bhp	9.2	8.2		
motor effic (all motors)	NEMA Hi	NEMA premium	NEMA Hi	
SCHW (secondary) loop gpm	1120	1000		
SCHW loop head	75.0	75.0		
SCHW pump effic	0.72	0.72		
SCHW pump bhp	29.5	26.3		
SCHW pump min flow	constant speed	20%		
Total CHW loop+pump $/ton	$ 560	$ 750		3
Total Chilled Water Loop Cost	$ 313,600	$ 375,000		
CW loop gpm (based on 2.5 gpm/ton)	1400	1250		
CW loop head	40.0	40.0		
CW pump effic	0.77	0.77		
CW pump bhp	18.4	16.4		
CW Loop $/gpm	$ 33	$ 38		3

	T-24 Base Case	T-1 Proposed Case	T-1 Standard Case	Footnote
CW Loop Cost	$ 46,200	$ 47,500		
Tower approach	15.0	10.0	10.0	
Tower size (tons)	690	590		
Tower gpm/hp	20 (=0.15 bhp/ton)	50 (=0.06bhp/ton)		
Tower fan control	single speed	2 speed		
Tower $/ton	$ 97	$ 144		3
Tower Cost	$ 66,930	$ 84,960		
HW loop gpm	300	300		
HW loop head	50	50		
HW pump effic	0.72	0.72		
HW loop bhp	5.3	5.3		
HW loop min flow	constant	20%		
HW loop $/gpm	$ 50	$ 63		3
HW Loop Cost	$ 15,000	$ 18,750		
Supply fan CFM	270,000	225,000		
Supply fan W/CFM	1.25	1.0	1.0	
supply fan bhp	453	302		
Supply fan temp rise	3.88	3.10		
Supply fan control	VSD	same	same	
AHU base cost $/cfm	$ 2.10	$ 2.10		3
Total AHU Cost	$ 567,000	$ 472,500		
Total Incremental Cost		$ 113,100		
Elec Util Rate	PG&E E-19S	PG&E E-19S		
Gas Util Rate	PG&E GNR-1	PG&E GNR-1		
Energy Cost Savings (vs Base)		$ 100,930		
Payback (yrs)		**1.1**		
Source Energy (kBtu/ft²-yr) (w/o receptacle)				
Percent Better Than T-24 (regulated end-uses)		**23%**		

1. The net incremental cost of a more efficient lighting system is assumed to be zero
2. VSD modeled using Trane 400 VSD EIR-FPLR curve from S. Taylor
3. Sources: Dupont Dobbs, 1996 CADMAC (California Demand Side Management Measurement Advisory Committee)
   CADMAC cost data compiled from manufacturers, distributors, retailers, contractors, utility program files, R. S. Means, etc
   Dupont Dobbs Engineers cost data based on 30 years HVAC design experience and current info from vendors (12/99)
4. Source: ASHRAE 90.1 life-cycle cost analysis (available in NBI Criteria Generator software)